REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-98-

0131

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the ti gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comm collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Direc Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Redu

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
December 31, 1997

3. REPORT TYPE AND DATES COVERED
Final Report, Sep 1, 1996-Oct 15, 1997

4. TITLE AND SUBTITLE
Sensor Management Research

5. FUNDING NUMBERS
F49620-96-1-0382

6. AUTHOR(S)
Avner Friedman
Keith Kastella

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Minnesota Center for Industrial Mathematics
University of Minnesota – 514 Vincent Hall, 206 Church St.
Minneapolis, MN
Lockheed-Martin Tactical Defense Systems
P. O. Box 64525 MS U1N28 St. Paul, MN 55164-0525

8. PERFORMING ORGANIZATION REPORT NUMBER
MCIM-Final Report

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Office of Scientific Research
110 Duncan Avenue, Suite B115
Bolling AFB, DC 20332

nm

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

19980205 062

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This grant is supporting development of mathematical foundations for sensor management systems. This year's accomplishments are in three areas: Extension of a Kalman-filter based discrimination metric to interacting multiple model filters; extension of sensor management based on Joint Multitarget Probabilities to incorporate multiple sensor modes and target classification; and development of fast methods to solve the Fokker-Planck equation for real-time non-linear filtering applications. To support sensor management representations of multi-target probability densities must be developed that model the uncertainty between quantities such as the number of targets, their locations and their class. To solve this problem and study it in a simple setting, the notion of Joint Multitarget Probabilities for detection, tracking, and target classification was developed and tested. In certain cases the time-evolution of these probabilities is characterized by a partial differential equation called the Fokker-Planck equation leading to a nonlinear filter. Several prototype nonlinear filters using the Alternating Direction Implicit scheme to solve the Fokker-Planck equation in real-time were formulated. In these applications it seems to offer significant improvement in estimation performance at a supportable cost in computational load.

DTIC QUALITY INSPECTED 4

14. SUBJECT TERMS
Data Fusion, Bayesian statistics, classical probability, discrimination, Kullback-Leibler information, numerical methods

15. NUMBER OF PAGES
6

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

1997 Final Report for AFOSR

Sensor Management Research

Grant Number: AFOSR/F49620-96-1-0382

Avner Friedman
Minnesota Center for Industrial Mathematics
School of Mathematics
University of Minnesota
127 Vincent Hall
206 Church Street, S. E.
Minneapolis, Minnesota 55455

Keith Kastella
Lockheed-Martin Tactical Defense Systems
P. O. Box 64524 - MS U1T23
St. Paul, Minnesota 55164-0525

1. Objectives: This project is developing mathematical foundations for sensor management systems. Sensor management can be viewed as the process of selecting sensors, sensor modes and sensor dwell points to optimize the probability density characterizing a set of targets in a region. Thus, there are two parts to this problem. In order to support this approach, representations of multitarget probability densities must be developed that are rich enough to model the uncertainty between quantities such as the number of targets in a region, their locations and target classes. Then, given this probability density, measures of sensor effectiveness must be computed and optimized. This work is a collaboration between Lockheed-Martin Tactical Defense Systems, the Minnesota Center for Industrial Mathematics (MCIM) and Mr. S. Musick at the USAF Wright Laboratory.

2. Status of Effort: Sensor management requires optimizing sensor effectiveness across multiple conflicting objectives such as a desire to localize and classify known targets while attempting to detect new ones as well. This requires joint representation of the probability density for the number, location and class of a collection of targets. In order to solve this problem and to study it in a simple setting, we developed the notion of Joint Multitarget Probabilities for detection and tracking. During the past year this was extended to the problem of sensor management with target classification.

A related issue that arises in this context is determining how these probability densities evolve in time. The resulting densities are often very complicated. Even in single target cases, determining the time evolution of these densities is a challenge requiring new algorithmic approaches. In certain cases this evolution is characterized by a partial differential equation called the Fokker-Planck equation (FPE) and its generalizations. Although this has long been known, solution of the FPE has generally been regarded as unfeasible for real-time applications. Now, recent advances in computers and numerical methods may have changed this. To explore the viability of real-time FPE solutions, we developed several solution schemes and applied them to test problems with very promising results.

Some of our past work on sensor management for multitarget/multisensor developed discrimination gain for the case of a collection of targets described by conventional Kalman filters. In a generalization of this work, a method for computing the expected discrimination gain was developed for multiple model Kalman filters. This is being applied in a more realistic setting under a transitioning Small Business Innovative Research program.

3. Accomplishments: This year's accomplishments are in three areas: Extension of a Kalman-filter based discrimination metric for sensor management to a more general class of filters; extension of sensor management based on Joint Multitarget Probabilities to incorporate multiple sensor modes and target classification; and the development of fast

methods to solve the Fokker-Planck equation for real-time non-linear filtering applications.

Expected discrimination gain is a useful general measure of sensor effectiveness that was developed for targets being tracked by Kalman filters. Real applications often require more sophisticated filters which characterize target motion in terms of both continuous dynamical states and discrete states referred to as dynamics modes. A measure of discrimination gain was derived to apply to this case. In this case, there are two factors that contribute to the expected discrimination gain: the reduction in uncertainty about the target's kinematics; and the reduction in the uncertainty about the target's flight mode, e.g. whether the target is turning or in straight and level flight. A conference paper has been accepted on this work [7] and a more detailed journal paper has been submitted [2].

Earlier work on discrimination gain for static detection problems [1] was generalized to the problem of dynamic targets and dynamic targets with classification and sensors with multiple modes to select from [8]. In this case, discrimination can be optimized by determining where to direct the sensors and which sensor mode to use. For example, in a test problem with a sensor that can either detect or classify targets, discrimination is initially optimized by using the sensor in its detection mode. After the targets have been detected and localized the classification mode begins to have high discrimination value. This method is very compute intensive. In collaboration with Mr. S. Musick, a simplifying scheme based on a product representation of the joint density is being developed [9].

In order to compute the expected discrimination gain when a sensor mode and dwell point is selected, the time evolution of the probability density between measurements must be computed. This can be determined by the Fokker-Planck equation FPE (or closely related equations). In collaboration with researchers at the U. of MN we explored several methods for solving the FPE in real time. With Dr. M. Kouritzin, a convolution-based scheme for altitude tracking was developed and evaluated [10]. Several techniques for solution of the FPE using finite difference schemes were explored. As part of his Master's degree work at the Minn. Center for Industrial Mathematics, Mr. A. Zatezalo developed and tested four FPE solvers against a model problem typifying tracking applications. Dr. Kastella supervised this work while Mr. Zatezalo interned with LMTDS-E in the summer of '96. Dr. N. Krylov is Mr. Zatezalo's advisor. Valuable insight into the proper way to treat the boundary condition for this type of problem was provided by Prof. Friedman. The four FPE solvers we studied [11] were: the Alternating Direction Implicit (ADI) scheme; the method of fractional steps; an Euler explicit scheme; and a multigrid scheme. For this problem ADI and the method of fractional steps were found to be about two orders of magnitude more efficient than the Euler explicit and multigrid schemes.

Based on this study, the Alternating Direction Implicit (ADI) scheme seems very promising for sensor management and non-linear filtering applications. ADI is a so-called O(N) algorithm, which means that its computational complexity grows linearly

with the size of the finite-element grid used to discretize the problem. In an effort to assess the feasibility of ADI-based non-linear filtering, a diverse set of model applications have been formulated. These model applications are: 1) low-SNR image tracking with nonlinear target dynamics and non-Gaussian measurements; 2) missile altitude tracking with severe multipath interference and; 3) joint tracking and identification using RADAR position measurements and range-profile measurements (an application suggested by Mr. Musick). Two conference papers on this work have been accepted for publication [11, 12], one journal paper has been submitted [3] and several more are nearing completion [4-6]. In all of these applications, NLF significantly improvements estimation performance at a supportable cost in computational load. For example, in low-signal/noise ratio image tracking, it provides an order of magnitude improvement in performance against maneuvering targets. In simulation tests for tracking in multipath interference, NLF successfully tracks targets that are essentially un-trackable by other means. In the joint tracking and recognition application, NLF reduces the time to classify the target by about 50%, compared to a direct maximum-likelihood classifier.

4. Personnel Supported:
Avner Friedman
Keith Kastella
Wayne Schmaedeke

5. Technical Publications:

Journal Publications:

1. K. Kastella, "Discrimination Gain to Optimize Detection and Classification", IEEE Transactions on Systems, Man and Cybernetics, Jan. 1997, Vol. 27, No.1, pp. 112-115.

2. W. Schmaedeke, K. Kastella, "Discrimination Based Sensor Management with Interacting Multiple Model Filters", submitted to IEEE Transactions on Systems, Man and Cybernetics.

3. K. Kastella, A. Zatezalo, "A Nonlinear Filter for Real-Time Joint Tracking and Identification", submitted to IEEE Transactions on Aerospace and Electronic Systems.

4. A. Zatezalo, K. Kastella, "Solution Schemes for Real-Time Nonlinear Filtering", in preparation

5. K. Kastella, A. Zatezalo, "A Nonlinear Filter for Low-elevation Target Tracking in Multipath", in preparation.

6. K. Kastella, A. Zatezalo, "A Nonlinear Filter for Low-SNR Maneuvering Target Detection and Tracking", in preparation.

Reviewed Conference Proceedings

7. W. Schmaedeke and K. Kastella, "Information based sensor management and the IMMKF", to appear, *Proceedings of SPIE Aerosense '98.*

8. K. Kastella, "Joint Multitarget Probabilities for Detection and Tracking", K. Kastella, SPIE AeroSense `97

9. S. Musick and K. Kastella, "A practical implementation of joint multitarget probabilities", to appear, *Proceedings of SPIE Aerosense '98.*

10. K. Kastella, M.A. Kouritzin, and A. Zatezalo, "A Nonlinear Filter for Altitude Tracking", 1996 Proceedings of the Air Traffic Control Association, pp. 1-5.

11. A. Zatezalo, K. Kastella, "Finite Differences and Nonlinear Filtering", to appear, *Proceedings of the 1998 International Conference on Nonlinear Problems in Aviation and Aerospace*, Daytona Beach, Fl.

12. K. Kastella and A. Zatazelo, "Nonlinear Filtering for Multipath Tracking", to appear, *Proceedings of SPIE Aerosense '98.*

6. Interactions/Transitions:

6.1 Conference Presentations:

K. Kastella, A. Zatezalo, "Nonlinear Filtering for Detection, Tracking and ID Algorithms", ONR Filtering and Tracking Workshop, Dahlgren, VA, May, 1997

Presentation to Naval Surface Warfare Center:

K. Kastella, "Discrimination based sensor management for detection, tracking and classification", - Dahlgren, May, 1997

6.2 Transitions:

An algorithm using discrimination-based sensor management with Interacting Multiple Model Kalman Filters (IMMKF) is currently being incorporated into a Phase I Small Business Innovative Research (SBIR) contract called "Sensor Management Across Multiple Platforms (SMAMPS)".

Wolfgang Kober
Data Fusion Corp.

9035 Wadsworth Pkwy, #1260
Westminster, CO 80021
(303) 421-7994
wkober@datafusion.com

7. Patent Disclosures
None

8. Honors
None